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ABSTRACT

The ENKA Project is concerned with two major problem areas: the conceptions of physical and chemical phenomena, central to an upper level course, held by compulsory school pupils (grades 7-9) and the implications from descriptions of pupils' conceptions and ways of reasoning for current teaching practice. To determine conceptions held, pupils were given a problem to solve and asked to explain how it was solved. This was accomplished by individual interviews or written tests in half a class period. Results indicate that: (1) Pupils have intuitive everyday conceptions of physical and chemical phenomena, such as electricity, heat, light and chemical reactions, before they receive instruction about them. (2) These everyday conceptions can be categorized. (3) Everyday conceptions within a particular field are not predictable but have to be discovered, and each field therefore has to be studied separately. (4) Everyday conceptions disrupt and impede the learning of the more adequate concepts contained in school courses. (5) Teachers are little acquainted with these everyday conceptions and their importance for learning. (6) The effect of school instruction in improving pupils' scientific thinking is not very large. Following selected examples of pupils' thinking related to electricity, matter, and optics, a brief discussion of on-going research is provided. (Author/JN)

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INITIAL PREMISES

The aim of the 9-year compulsory school is to promote the development of all its pupils, and it is therefore desirable that all individuals should, during their school career, experience success and the feeling that they are capable. This in turn will enhance their motivation for learning.

To achieve this aim, it is essential to know where the pupils stand initially and to adjust the teaching accordingly. But accumulated teaching experience has shown that the course-requirements of the upper level (grade 7-9) physics and chemistry greatly exceed what pupils are capable of grasping. Existing physics textbooks, for example, present a comprehensive, abstract course containing mechanics, heat, optics, electricity, solid state physics, atomic physics, nuclear physics, astronomy, meteorology etc. To find time for all these things, teaching has to be "streamlined", whith the result that pupils are pushed at high speed along the narrow rails of cookery book laboratory experiments and fill-in tasks.

Upper level physics and chemistry teaching, as reflected by the teaching materials, is therefore hardly compatible with the aims of the compulsory school. The gap between the pupils' level of reasoning and the conceptual demands of science courses is far too great. We will therefore have to make an effort to discover and describe the pupils' initial position and then adept teaching accordingly. The EKNA project is conceived as part of this effort.

The basic approach of the EKNA group has partly been derived from the work of Jean Piaget. We conceptualize the individual as active and searching for knowledge. He (or she) constructs his view of the world through his own thoughts and actions. Piaget has also shown, with a wealth of detail, how widely young persons' concepts and ways of reasoning differ from those of adults. As teachers we have not yet assimilated this fact where the teaching of physics and chemistry is concerned. We must therefore find out the pupils' concepts and ways of reasoning.

This is to a large extent a question of stimulating them to express their own thoughts in words and actions without fear of incurring ridicule. They, as pupils, need to feel that the teacher really cares about what, and how, they think even if it is not completely correct.

This is easier said than done. The teacher feels constrained to cover the whole of a difficult and voluminous course and therefore feels unable to spend time in listening to, and discussing pupils' answers, especially if those answers are incomplete or incorrect. The pupils are given few opportunities to think about problems, be creative, or express themselves. Mass-produced laboratory kits of limited flexibility place obstacles in the way.

This pattern must be changed. Perhaps the basic approach presented by the EKNA group will release new energy and ideas. A wide-ranging debate is needed in order to penetrate the implications of this approach at classroom level. The research of the EKNA group can make a significant contribution by discovering, revealing and describing the conceptions, in various fields, which are commonly held by the pupils.

Summing up: For about two decades, upper level compulsory school pupils have spent a great deal of time and trouble trying to understand physics and chemistry teachers' way of thinking. The time has now come for another two decades to be spent discovering how pupils think.

SCIENTIFIC BACKGROUND

It is possible in scientific thinking to distinguish aspects of form and content. Common forms of thought, applicable to various types of content, include for example controlled experiments, proportionality and reasoning with models. Ideas of content include for example that of the rectilinear transmission of light and that of electricity as constituting charges in motion.

Forms of thinking and conceptions of content can be used very differently by different individuals. One person may think analytically, another intuitively. One person may be inclined to reproduce what he has learned to use within a particular field, while another may endeavour to create new combinations.

The analytical-intuitive and reproductive-creative concepts describe different cognitive styles towards a given content. We should also mention that thinking and emotional experience are closely interconnected.

Of the above mentioned aspects of scientific thinking - form, content, cognitive style and emotional experience - the aspect of form has been the most researched. This was due to the publication in the fifties of an interesting and stimulating work on forms of scientific thinking, viz The Growth of Logical Thinking from Childhood to Adolescence, GLT (Inhelder and Piaget, 1958). The research based on the GLT has supplied us with detailed knowledge concerning the ways in which pupils think when trying to employ proportionality, controlled experiments and other forms of thinking in given situtations, e.g. a pivoted lever, a pendulum or the projection of shadows. All investigations have indicated, moreover, that only a small proportion of children between the ages of 12 and 15 (about 10 per cent) has mastered these forms of thinking. Since proportionality, controlled experiments and thinking in terms of models, for example, are so widely used in science teaching, GLT can be said to have done a great deal to bring attention to the gap existing, in most countries, between the pupils' ways of reasoning and the very high conceptual demands of science courses.

The aspect of form in scientific thinking having been relatively well researched, the EKNA group has chosen to concentrate on the aspect of content. Quite simply, we study sections of the content of the upper level course and study the pupils' reasoning within those sections. The main method is that of presenting a problem to the pupil, asking for a solution and also asking the pupil to explain how he of she worked it out. This is done by individual interviews or written tests in half a class. The problems are presented with the aid of concrete experimental material.

The EKNA group's concentration on content does not imply that the aspect of form has been ignored. In point of fact, form and content are not easily segregated, the question being more one of emphasis. On the other hand, our investigations do not include cognitive style and emotional experience. These aspects lie outside the range of the EKNA group's competence at present.

PROBLEMS

Given the background and premises which have now been described, we can proceed to define the two main problems with which the EKNA project is concerned. The first of these is to find an answer to the question: "What conception of physical and chemical phenomena, central to the upper level course, do compulsory school pupils have?" This will involve making new discoveries as well as enlarging on existing knowledge. At present the main emphasis is on physics, but chemistry is being increasingly incorporated into our investigations.

The second problem is: "What are the implications of our descriptions of the pupils' conceptions and ways of reasoning for current teaching practice?" We have to analyse and discuss these consequences and point to conceivable ways of bringing about improvements. Practical and detailed testing of these possibilities falls outside the scope of EKNA's activities, and indeed will be so extensive as to demand a special project.

RESULTS

General

One way of summarizing the results of the EKNA project is as follows.

1) Pupils have intuitive everyday conceptions of physical and chemical phenomena, such as electricity, heat, light and chemical reactions, before they receive instruction about them.

2) These everyday conceptions can be categorized.

3) Everyday conceptions within a particular field are not predictable but have to be discovered, and each field therefore has to be studied separately.

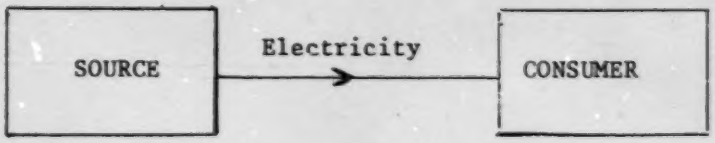
4) Everyday conceptions disrupt and impede the learning of the more adequate concepts contained in school courses.

5) Teachers are little acquainted with these everyday conceptions and their importance for learning.

6) The effect of school instruction in improving pupils' scientific thinking is not very large.

Example I. Electricity

A child pondering electricity in the home observes that there is one lead to the lamp in the ceiling, that there is one lead on the vacuum cleaner, and so on. These observations may suggest a source-consumer model concerning electricity:



The electricity or current is contained in a source, it flows to the consumer and is consumed there. This model is reinforced by the way in which we talk about electricity in everyday life. Swedish children are told not to waste current, they are told that it costs money, and so on.

About 80 per cent of senior level pupils employ a source-consumer model for electricity. Some think of the bulb in figure 1 A, below, emitting light, and others imagine that a bulb can be connected as in figure 1 B and a small amount of current drawn off. Several pupils have the idea of opposing currents (see figure 1 C), and they imagine that a bulb consumes current (figure 1 D).

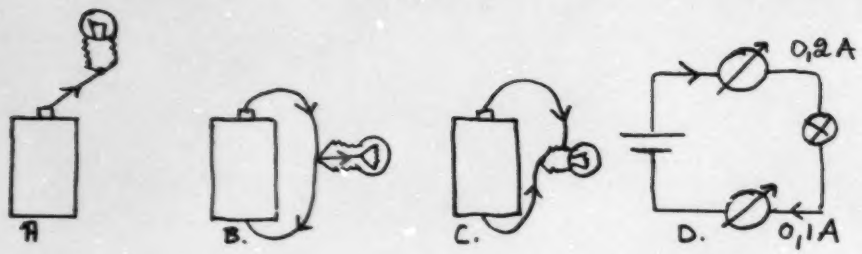


Figure 1. Various examples of a source-consumer model of electricity.

Our survey in upper level schools involved 550 pupils, who all tackled six written problems, while 25 were interviewed as well. We find that the source-consumer model is still going strong despite considerable teaching efforts (two hours weekly for six months in grade eight). We are failing to teach about 80 per cent of the pupils the model of the closed circuit.

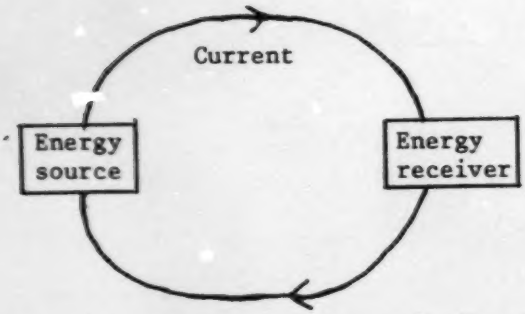


Figure 2. The closed circuit model

An electricity study has also been undertaken in the first two grades of upper secondary school, in the Science, Technology, Economics, Liberal Arts, Social and Social Science Lines (involving 536 students in Jönköping, written tasks). The source-consumer model predominates (65 per cent of students approx.). This study also revealed considerable differences between the sexes with regard to all the problems that were set. One question asked was whether or not the bulb would light up when connected as shown below. (About ten connections were presented altogether.)

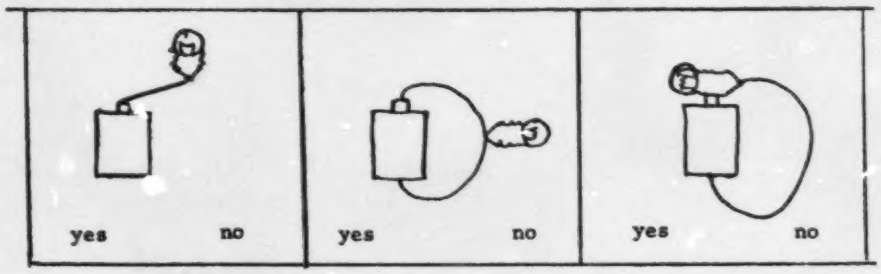


Figure 3. Will the bulb light up?

56 per cent of the boys replied correctly concerning all the connections, but only 9 per cent of the girls did so. The students in non-science lines consistently obtained results far inferior to those of students in the Science and Technology Lines. Girls in the Social Line did worst of all, with hardly a single correct answer.

A considerable proportion of trainee class teachers are recruited from non-science lines of upper secondary school. Over 40 per cent of the trainees admitted in the autumn term 1980 came from the Social Line, which suggests that the teaching on electricity in schools has been caught in a vicious circle. At the very age (7-12 years) when they start getting interested in science, e.g. electricity, pupils are taught by teachers coming pre-dominantly from lines of upper secondary school where little is known about electricity.

Example 2. Matter

To our knowledge, very few studies have been made of the conceptions held by pupils aged between 12 and 16 concerning matter. This applies particularly to chemical processes. But matter is an important part of science teaching at the upper level of compulsory school, and the EKNA group is therefore trying to chart pupils' thinking in this field. The purpose of the publication "Matter: some questions", is to define the appropriate direction of research. Following an analysis of the role of the atomic hypothesis in science teaching, four questions are identified on which EKNA's interest is focused:

1) How do senior level pupils describe and explain phases and phase transitions and various kinds of chemical interaction?

2) To what extent do senior level pupils employ the scientific concept of the atom when explaining and predicting events?

3) What alternative explanatory models are used by those pupils who do not employ the scientific concept of the atom?

4) What meaning do the word atom and textbook pictures of atoms have to pupils?

As a first step towards answering question 1, we have chosen a classical experiment which is commonly used in senior level chemistry teaching. A piece of steel wool is suspended in a balance pan, counterbalanced and ignited. As it burns, the pan containing the steel wool gradually sinks. The pupils are asked:

a) to predict what will happen if a lighted match is inserted underneath the counterbalanced steel wool

b) to describe and explain why the pan containing the steel wool sank after combustion

These questions were answered in writing by about 600 pupils in grades 6-9 (group tests) and orally by about 25 pupils (interviews).

The following were among the results obtained:

Just over 10 per cent of the pupils in grades 8 and 9 volunteer a chemically acceptable explanation. (Oxidation is dealt with in grade 7.) These pupils reply, for example, that something is added from the air or that the steel wool combines with oxygen and thus grows heavier. The rest of the pupils offer an abundant variety of both physical and chemical explanations, e.g.:

- The steel wool has been compressed by the heat, and this makes it heavier.
- The air in the steel wool is expelled by the heat, and this makes it heavier.
- The steel wool is converted to carbon, which is heavier.

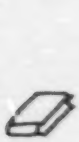
The analysis of the pupils' replies reveals a very diffuse idea concerning the nature of a gas. The interviews show, that the pupils think that oxygen=air=gas. Thus the three terms are considered more or less synonymous. In addition, the pupils believe that air is weightless.

The pupils seldom reason in terms of atoms. Insofar as they do, they transfer properties of observable reality to the hypothetical world of the atom. For example, we find that pupils think of atoms as expanding and contracting, burning up and conducting heat.

Example 3. Optics

Putting the following problems to upper level pupils, we obtain a number of interesting answers.

Problem



Pupil and physics teacher are talking about vision.

Teacher: Explain how you can see that book.

Pupil: Signals go along nerves between the eyes and the brain.

Teacher: Yes, that's what happens between the eyes and the brain, but there is some distance between your eyes and the book. Does anytning happen between them?

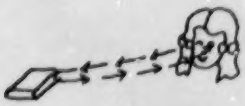
How would you answer? Draw and explain!

Some answers

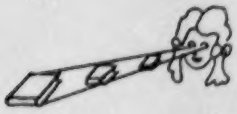
- Nothing happens between the book and the eyes.

- The girl focuses her lens on the book. The eyes concentrate on the book.

- Rays go from your eyes to the book, so that you can see the book.



- The eyes emit some kind of ray which returns to the head and tells it.



- The book is reproduced as a picture on the retina.

About 600 pupils in grades 6-9 answered this and five other written questions about light and its properties (written tests). About 25 pupils were interviewed on the subject of light and its properties. Here are some of the results obtained.

Only 20 per cent of pupils shows signs of having understood that light is something which exists and propagates in space. But this is the key idea of optics, and the upper level optics course implicitly assumes that pupils have grasped it. It is therefore reasonable to assume that the optics course in its present form means little to 80 per cent of the pupils.

Pupils alternative ideas vary a great deal, but the concept of visual rays, looks, impulses etc. emitted by the eye is one which recurs quite often in replies to questions about vision. (50 per cent of the pupils employ this idea in at least one of three tasks.)

Once again, our results indicate that we are dealing with intuitive, everyday concepts of light and vision which are not appreciably influenced by teaching. Light, in everyday parlance, means both "experience of light" and "source of light". We seldom use the word to denote the light passing e.g. at this instant from the printed page to the reader's eye. We do not see it, but we know that it is there. (This is an understanding which it took mankind some 2 000 years to accomplish.) If we do not talk to our children about physical light, they are hardly likely to form any ideas of their own on the subject. The idea of looks, visual rays etc. probably emanates from the many idioms of everyday speech referring to the eyes, as being active and emitting something. We give looks and throw glances. Looks are felt, they hearten and chill, eyes flash, and so on.

ON-GOING RESEARCH

Qualitative analyses of pupils answers

In collaboration with Dr. Rosalind Driver at the Centre for Studies in Science Education, Leeds University, we are now investigating pupils' ideas in three new fields, viz:

A. Concervation of mass in chemical processes.
B. Everyday chemical phenomena associated with oxidation.
C. Photosynthesis.

Field tested paper and pencil tasks are being given to random national samples of pupils in England and Sweden. The analysis will focus on qualitative differences in the pupils' explanations and on a comparison between the two countries. The pupils taking part are aged between 13 and 15. Supplementary interviews are planned.

Efforts to change pupils' everyday conceptions

All the EKNA studies carried out so far have shown that pupils have everyday conceptions concerning chemical and physical matters and that these ideas are not superseded to more than a slight extent (10-20 per cent) by the more appropriate concepts of physics and chemistry as taught in schools. Teachers naturally wonder what they can do to remedy this unsatisfactory state of affairs. As we see it, there are two things which need to be done. Firstly, a constructivistic view of learning must be put in place of the prevailing passive, receptive one. Secondly, teaching processes must be created at detail level which will lead to permanent conceptual changes. The EKNA group has started work in this direction in the field of electricity. On the strength of the research findings, exploratory teaching has been followed by the compilation of a teacher's guide for electricity, "One way of teaching D.C. circuits", by Christina Kärrqvist. Two learning studies have been undertaken on the basis of this guide. In the first study, four pupils were given individual tuition in front of a television camera (about 12 hours per pupil), and in the second a controlled experiment was conducted in grade 6. The pupils in the latter experiment will be given a follow-up test in about six months' time. The TV study is

aimed at describing learning difficulties and ways in which the teacher can carry on a dialogue with the individual pupil so as to help him or her to form new concepts. The teacher's guide will be published in the spring 1983. The learning studies will be analysed as work for a Ph. D. degree, and it should be possible for the findings to be published in 1983/84.

MATERIAL COMPILED

Ten reports have been published in Swedish. They deal with pupils conception of electricity, boiling, melting, light and chemical reactions.

Reports in English

Andersson, B. & Kärrqvist, C.: The Pupils' Conceptions of Light and its Properties. EKNA-report No. 8, 1982.

Andersson, B. & Renström, L.: Oxidation of Steel-wool. EKNA-report No. 6, 1982.

Articles in English

Andersson, B.: Some Aspects of Childrens Understanding of Boilingpoint. Paper presented at Seminar on Science Teaching, Leeds, 1979-09-17--21. The EKNA Project.

Andersson, B.: Pupils' Understanding of Some Aspects of Energy Transfer. Paper presented at the symposium Science and Society: A pedagogical approach to energy and energy resources in the comprehensive secondary school, Notodden, Norway, 1980. Available from the EKNA Project.

Andersson, B. & Kärrqvist, C.: Pupils' Understanding of Light and its Properties. Unpublished manuscript. The EKNA Project, 1982.

Six working papers have been prepared as part of the collaboration with the University of Leeds.

1. Andersson, B. & Renström, L.: How Swedish Pupils, Age 12-15, Explain the "Sugar in Water"-problem. The EKNA Project, 1982.
2. Andersson, B. & Renström, L.: How Swedish Pupils, Age 12-15, Explain the "Exhaust"-problem. The EKNA Project, 1982.
3. Andersson, B. & Renström, L.: How Swedish Pupils, Age 12-15, Explain the "Disprin"-problem. The EKNA Project, 1982.

4. Andersson, B. & Renström, L.: How Swedish Pupils, Age 12-15, Explain the "Phosophorus"-problem. The EKNA Project, 1982.

5. Andersson, B. & Renström, L.: How Swedish Pupils, Age 12-15, Explain the "Copper-pipe"-problem. The EKNA Project, 1982.

6. Andersson, B. & Renström, L.: How Swedish Pupils, Age 12-15, Explain the "Rusty Nails"-problem. The EKNA Project, 1982.

This joint project is described in a short memorandum by Dr. Rosalind Driver, Centre for Studies in Science Education, University of Leeds, and Ass. Prof. Björn Andersson of the EKNA project, entitled "Leeds-Göteborg Study - Pupils' Content-Oriented Reasoning in Science".